

# A Study of the Unidentified Gamma-Ray Source 3EG J1828+0142

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April 23, 2001

## Abstract

We present a study of the radio environment of the gamma-ray source 3EG J1828+0142. This source presents a very high variability index in its gamma emission and a steep high-energy spectral index  $\Gamma \sim -2.8$ . Large-scale radio maps at different frequencies show the presence of a shell-type non-thermal structure when the diffuse emission from the Galactic disk is eliminated. At small scales, VLA radio images reveal the existence of several weak point sources within the 95 % gamma-ray confidence location contour. Most of these sources present non-thermal spectral indices, but it is not clear whether they are extragalactic or not. We discuss the possibility of a scenario where the large structure is a SNR and one of the compact radio sources is an isolated black hole also produced in the original supernova explosion. The black hole could be responsible for the variable gamma-ray emission according to Punsly's (1998) model. INTEGRAL observations with IBIS imager could detect the inverse Compton and blueshifted pair annihilation radiation from the relativistic electron-positron jets of the hole. Some estimates are presented in this regard.

## 1 Introduction

The best estimated position of the gamma ray source 3EG J1828+0142 is at  $(l\ b) \approx (31.9^\circ, 5.8^\circ)$ , according to the Third EGRET catalog (Hartman et al. 1999). There are not known potential galactic counterparts like hot massive stars, supernova remnants (SNR) or young pulsars within the positional error box (Romero et al. 1999). The source is very variable over timescales of months (Torres et al. 2000). No strong radio source that could be identified with a blazar is found within the 95 % confidence contour of the gamma-ray emission. The high-energy spectral index  $\Gamma = -2.76 \pm 0.39$  ( $F \propto E^\Gamma$ ) is steeper than what is expected for most galactic gamma-ray sources. All these features make of 3EG J1828+0142 a very puzzling object.

In this paper we present both large and small scale radio maps of the region where this high-energy source is located. These maps could provide some clues about the origin and nature of 3EG J1828+0142.

## 2 Large-scale radio maps

We have studied the surroundings of 3EG J1828+0142 using radio data from the large-scale surveys by Haslam et al. (1981) and Reich & Reich (1986). Small-scale VLA observations from the NVSS Sky Survey by Condon et al. (1998) were used for a complementary study of the emission within the 95 % confidence location contour. We have applied a well-proven Gaussian filtering technique to the radio images (e.g. Combi et al. 1999) in order to remove the background contamination from the large-scale non-thermal disk emission.

In Figure 1, upper panel, we show a map of the radio field around 3EG J1828+0142 at 1.4 GHz. The probability location contours of the gamma-ray source are superposed to the radio image. A large, shell-type structure can be clearly seen. The outer boundary has been encircled in the figure. It is a weak source (the integrated flux density is  $18.2 \pm 2.1$  Jy at 1.4 GHz) with a low surface brightness that very much resembles a typical SNR. The identification is confirmed by the non-thermal spectral index found for the radio emission:  $\alpha = -0.72 \pm 0.18$  ( $S_\nu \propto \nu^\alpha$ ). The gamma-ray source is located on the boundary of this new SNR.

The fact that the gamma-ray emission is highly variable rules out the possibility that the source be the result of the interaction of the SNR with a cloudy medium as it has been suggested for other unidentified gamma-ray sources (e.g. Combi et al. 1998). A pulsar origin is also discarded by the variability levels and the steep spectrum. The gamma-ray emitting object, however, could be a compact remnant left by the SN explosion if it is a black hole instead of a pulsar. An isolated black hole would not undergo steady accretion from a stellar companion and consequently it should not be a strong X-ray source. Moreover, if the whole is charged and a strong magnetic field is supported by an orbiting opposite-charged ring or disk, as suggested by Punsly (1998), the system could produce relativistic leptonic jets, which can emit inverse Compton (IC) and annihilation gamma-rays (see Romero et al., these proceedings, for additional details of the model). The jets would also generate synchrotron radio emission, and hence the source should have a weak non-thermal counterpart.

### 3 Point-like radio sources in the field

In order to find the potential radio counterpart of the gamma-ray source we have used VLA images of the region within the EGRET 95 % confidence contour. The lower panel of Figure 1 shows the point-like radio sources visible at 1.4 GHz with flux densities above 5 mJy. In Table 1 we list the characteristics of these sources. Most of them have no entry in any current catalog. We have computed spectral indices when observations at other frequencies were available. For instance, source No. 9 corresponds to TXS B1825+016, with a flux density of 278 mJy at 365 Mhz (Douglas et al. 1996). Source No. 11 has been detected at 3900 MHz with a flux of 61 mJy (Torres et al. 2000) and source No. 15 is at the position of PNM J1827+0201, which presents a flux of  $\sim 49$  mJy at 4.85 GHz (Griffith & Wright 1993). For those sources not detected at 5 GHz in Condon et al.'s (1994) survey we have estimated upper limits for the spectral index. Many sources have non-thermal spectra and can be considered as potential radio-counterparts of the gamma-ray source, if the latter is produced by a magnetized black hole.

### 4 Discussion

The large angular size of the new SNR suggests that it is a nearby source. Applying the  $\Sigma - D$  relationship derived by Allakhverdiyev et al. (1988) for shell-type remnants of low surface brightness, we estimate a distance of about 1 kpc. The radius of the remnant, then, would be  $\sim 30$  pc and its age  $\sim 4 \times 10^4$  yr, assuming standard values for the particle density of the ISM and the original energy release (Spitzer 1998). Since the gamma-ray source is located on the boundary of the remnant, the hypothetical black hole should have a birth velocity of  $\sim 700$  km s $^{-1}$ . Although high, such a velocity is not unreasonable in the light of the recent estimates of Lyne & Lorimer (1994) for the birth velocities of radio pulsars.

The spectral energy distribution of a magnetized black hole in isolation (see Figure 2) has a broad peak at MeV energies, where the blueshifted annihilation radiation exceeds the synchrotron self-Compton emission. Adopting a set of standard parameters for the hole ( $M = 4 M_\odot$ ,  $B = 10^{11}$  G), the peak luminosity results  $\sim 1.8 \times 10^{35}$  erg s $^{-1}$  at  $\sim 6$  MeV (Punsly et al. 2000). At a distance of 1 kpc this implies a flux on Earth of  $\sim 1.5 \times 10^{-4}$  ph cm $^{-2}$  s $^{-1}$ . The source, consequently, should be detected by the Imager

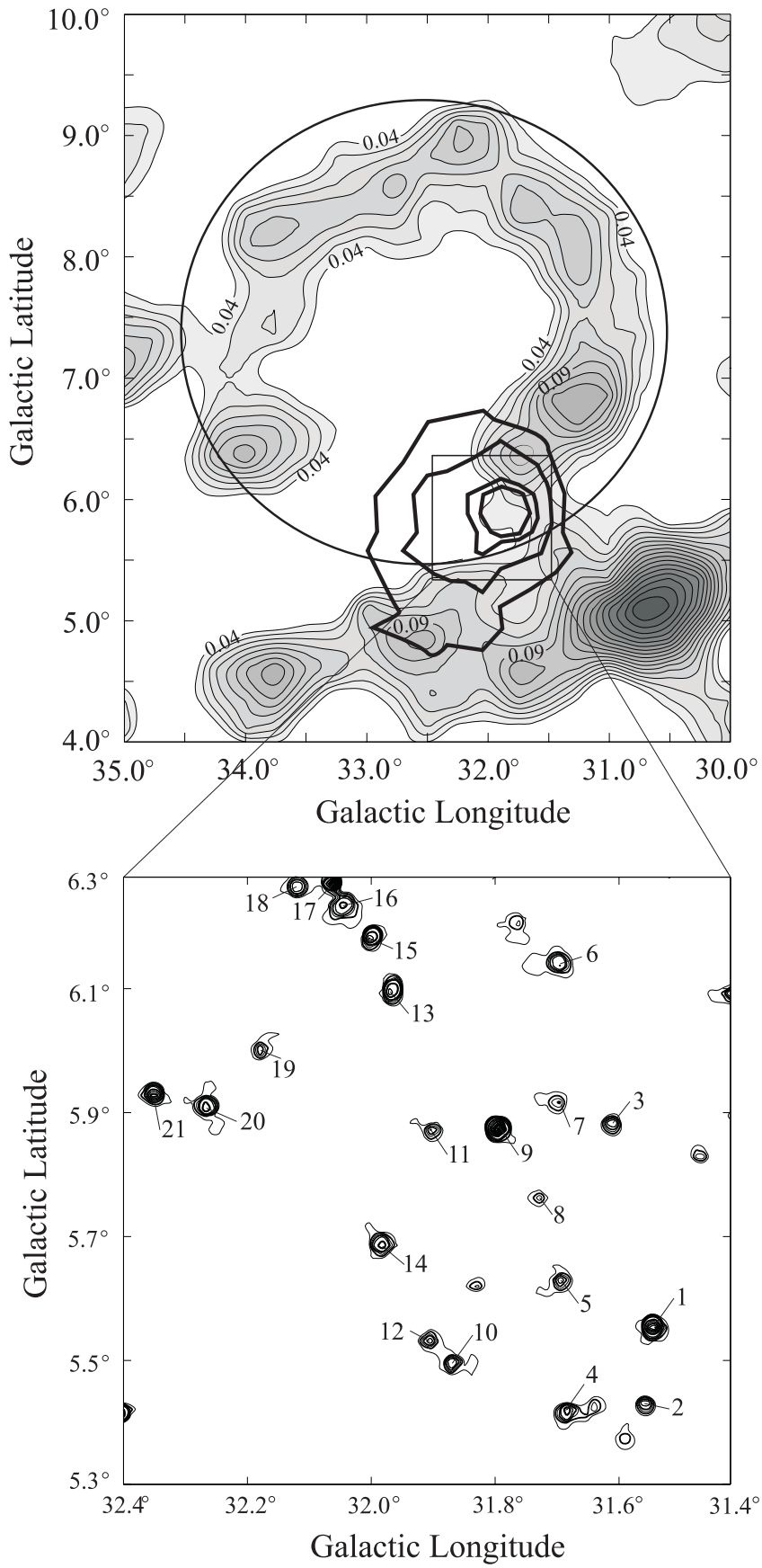


Figure 1: **Upper panel:** 1.4-GHz continuum map of the region around 3EG J1828+0142. A Gaussian filtering beam of  $90 \times 90$  has been applied to remove the diffuse background emission. Radio contours are shown in steps of 0.01 K starting at 0.04 K. The noise level is 0.02 K. Probability confidence contours for the location of the gamma-ray source have been superposed. **Lower panel:** Point-like radio sources at the same frequency, detected by the VLA within the 95 % probability confidence contour of the gamma-ray source.

Table 1: Point radio sources inside the 95 %  $\gamma$ -ray confidence contour. (Flux density measured at 1.4 GHz)

Source No	Coordinates (l,b)	Flux (mJy)	$\alpha$
1	(31.53,+5.56)	51.2	< -1.8
2	(31.55,+5.44)	14.6	< -0.84
3	(31.6,+5.89)	15.6	< -0.89
4	(31.67,+5.42)	32.9	< -1.4
5	(31.69,+5.64)	12.8	< -0.74
6	(31.7,+6.14)	35.9	< -1.5
7	(31.7,+5.92)	10.6	< -0.59
8	(31.72,+5.77)	7.30	< 0.3
9	(31.78,+5.88)	79.7	-0.9
10	(31.86,+5.5)	22.0	< -1.23
11	(31.89,+5.88)	13.8	1.34
12	(31.89,+5.54)	28.1	0.34
13	(31.96,+6.1)	46.4	< -1.75
14	(31.98,+5.69)	25.1	< -1.2
15	(31.99,+6.19)	43.5	0.10
16	(32.04,+6.24)	69.1	0.48
17	(32.07,+6.29)	84.2	< -2.2
18	(32.12,+6.27)	18.7	< -1.0
19	(32.17,+6.0)	12.6	< -0.72
20	(32.27,+5.91)	29.4	< -1.3
21	(32.35,+5.93)	41.2	< -1.65

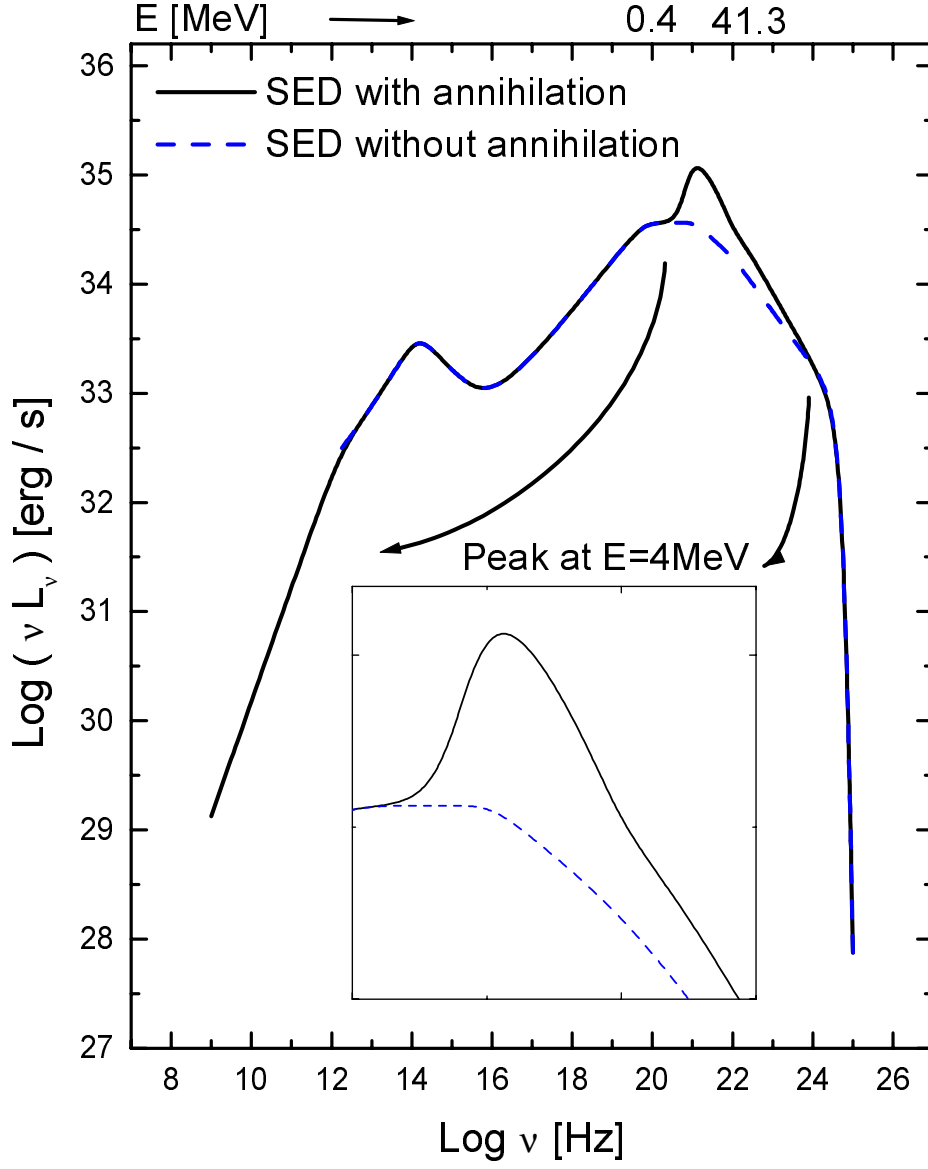


Figure 2: Spectral energy distribution for a magnetized black hole of  $4 M_\odot$  with a field of  $10^{11}$  G.

IBIS of the INTEGRAL mission. Frequent observations could provide more information on the variability of the emission. Spectral decomposition in the range 15 KeV – 10 MeV should reveal the existence of a luminosity peak at a few MeV. The exact position of the peak can be used to determine the Doppler factor of the beamed radiation. The improved source location will also allow to restrict the number of possible radio counterparts given in Table 1.

## 5 Conclusions

We report the discovery of a new and large SNR, till now masked by the diffuse background radio emission of the Galaxy. The variable gamma-ray source 3EG J1828+0142 is located on the outer boundary of this remnant. We suggest that this source could be a magnetized black hole produced by the original supernova explosion. The hole would have a transverse birth velocity of  $\sim 700 \text{ km s}^{-1}$  and an age of  $\sim 4 \times 10^4 \text{ yr}$ . Gamma-rays are expected from electron-positron annihilations and synchrotron self-Compton losses in the jets generated by the hole. A detailed model (Punsly et al. 2000) predicts a peak luminosity in the spectral energy distribution of  $\sim 1.8 \times 10^{35} \text{ erg s}^{-1}$  at  $\sim 6 \text{ MeV}$ . Imager IBIS of the INTEGRAL mission could test this hypothesis on the nature of 3EG J1828+0142 through:

- Detecting the predicted peak of the spectral energy distribution at MeV energies.
- Providing a better source location that enables to identify the expected weak radio counterpart.
- Measuring with high confidence the level of variability.

If the identification with a magnetized black hole is supported by the observations, then IBIS data can be used for:

- Estimating the actual value of the Doppler factor of the jet flow (from the blueshifted annihilation peak).
- Estimating the particle density in the jet (from the integrated annihilation line luminosity).
- Clarifying the mechanism that produce the gamma-ray variability.

At present time, it is not known whether charged and rotating (Kerr-Newman) black holes can exist in isolation. If stable configurations of black hole plus magnetosphere as those proposed by Punsly (1998) actually occur in the universe, then some variable gamma-ray sources like 3EG J1828+0142 could be their high-energy manifestations. The INTEGRAL mission, with the fine imaging capability and spectral sensitivity of IBIS instrument, could be a fundamental key to unveil the existence of such mysterious objects.

## ACKNOWLEDGEMENTS

This work has been supported by CONICET, ANPCT (PICT No. 03-04881) and Fundación Antorchas. G.E.R. is very grateful to the organizers for a travel grant that made possible his participation in the Workshop.

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